

Off-axis-NOTE-SIM-0016

Fiducial volume of the RPC detector

September 7, 2003
Version 1.0

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Abstract

Fiducial cuts in a low density detector may lead to a significant loss of an effective mass of the detector. Detailed studies of electron identification efficiency and all sources of backgrounds as a function of the position of the interaction inside the detector indicate that a detector with transverse dimension of 15 m or more will have an effective fiducial mass of the order of 75% of the total mass of the detector.

1 Introduction

The spatial extent of neutrino events in a low density detector is quite large. Particles produced in low energy neutrino interactions are emitted at relatively large angles, typically 20 degrees or so. They often have energies below the inelastic reaction threshold, hence they will range out rater than shower inside the detector. With detector density of the order of 0.7 g/cm^3 the range of 0.5 GeV article is 3 meters or so, hence a significant fraction of the event energy can escape detection unless a very stringent fiducial volume cuts are applied. Such cuts may lead to a significant loss of the fiducial volume of the detector.

2 The Method

We used a standard reconstruction and analysis procedure[1]. A figure of merit (FOM), defined as

$$FOM = \frac{\text{signal}}{\sqrt{\text{background}}}$$

is used to quantify the physics potential of a detector. This number depends on the detector parameters as well as on the unknown physics parameters. In this analysis a detector at a distance of 735 km from Fermilab and 10 km off axis was assumed. It was further assumed that $\Delta_{23} = 0.0025 \text{ eV}^2$, $\sin^2 2\theta_{13} = 0.05$ and $\delta = 0$. The FOM is computed assuming 250 kton-year exposure with 85% fiducial volume.

The data sets corresponding to "12 cm" detector are used as described in [2]. The finite fiducial volume is simulated by ignoring all hits with transverse distance from the interaction point exceeding a Δx cut for the transverse fiducial studies or the longitudinal distance exceeding a Δz for the longitudinal fiducial studies.

The background consists of several contributions: intrinsic ν_e component of the beam, NC and CC ν_μ interactions. As the interaction point is coming closer to the detector edge the efficiency of the electron identification, and thus the number of signal events, typically drops, whereas the number of accepted background events goes up.

All the cuts are kept unchanged for all interaction positions studied. This is the simplest case, but certainly not optimal. In practice one may adjust the cuts or even the analysis strategy as a function of the position of the interaction. Consequently, one should consider the results shown here as a conservative, worst case limit.

3 Results, differential

Fig. 1 shows the evolution of the electron identification and background samples as a distance from the edge of the detector. All the numbers refer to a 250 kton-year

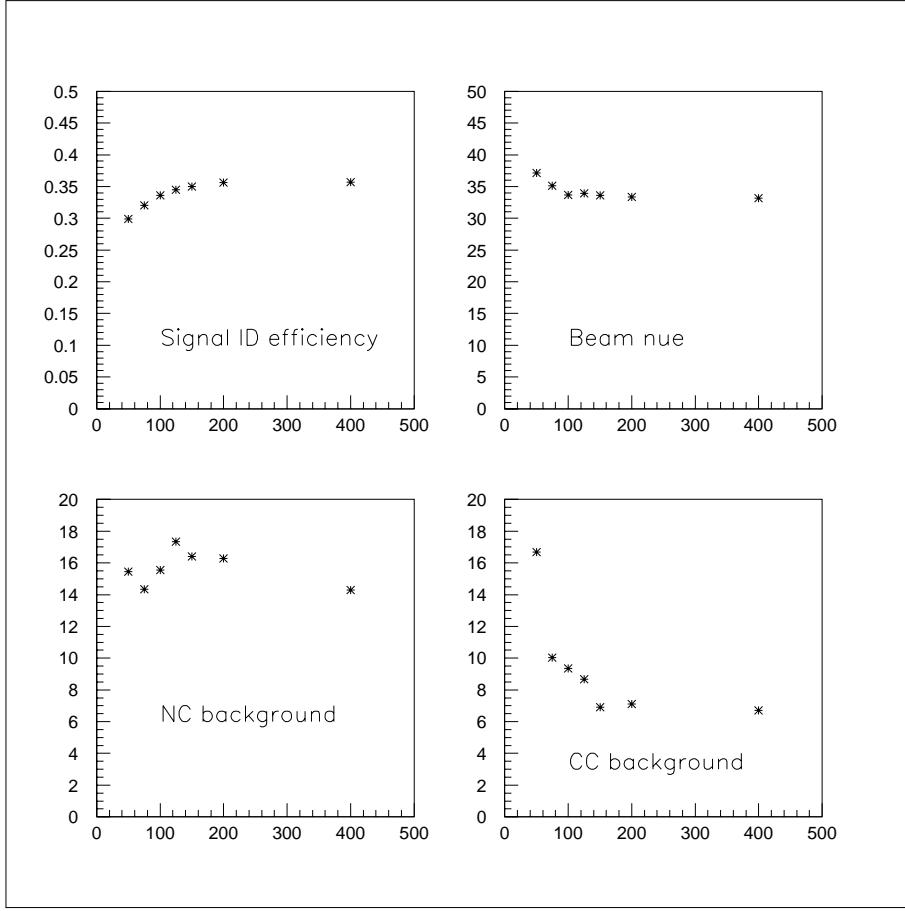


Figure 1: Top right: Efficiency for detection and identification of signal events (ν_e interactions due to oscillations), as a function of a distance, in cm, from the edge of the detector. Top left: Beam ν_e background . Bottom left: Background due to NC events, Bottom right: Background due to ν_μ CC events.

85% efficiency exposure of a detector element located at the given distance from the transverse edge.

A number of NC background events remains unchanged, whereas the efficiency for the detection of oscillated ν_e 's starts to deteriorate once the event vertex approaches the transverse boundary of the detector. In the neutrino events originating close to the boundary some fraction of the energy will escape, thus leading to an underestimate of the total neutrino energy. This will result in the increased beam ν_e background, which has harder energy spectrum than the signal events. In a similar manner, muons escaping the detector may be mis-identified as electrons, thus leading to the increased background from ν_μ CC events.

A similar problems arise at the end of the detector, as shown in Fig.2. Here all the hits downstream of the interaction point further than the cut value were

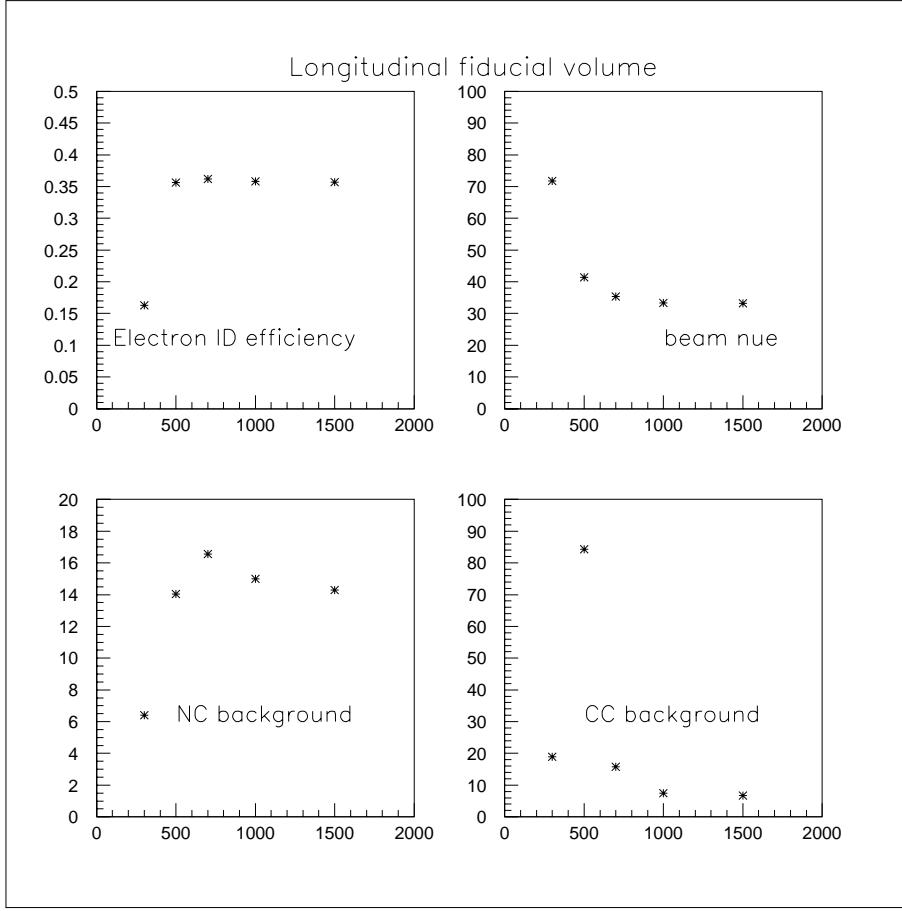


Figure 2: Top right: Efficiency for detection and identification of signal events (ν_e interactions due to oscillations), as a function of a distance, in cm, from the downstream end of the detector. Top left: Beam ν_e background . Bottom left: Background due to NC events, Bottom right: Background due to ν_μ CC events.

ignored. Signal detection efficiency starts to suffer when some of the energy of the signal events escapes detection. This happens at the distances of the order of 4 meters or less from the downstream end of the detector. For the same reason as in the transverse case, this leakage results in an increase of the beam ν_e background. Neutral current background will be reduced as the visible energy distribution of the NC events is steeply falling. A 'resonant' increase of the ν_μ CC background for the events occurring 4-6 m before the end of the detector is related to the total energy window which is used in the analysis.

4 Results: global

Given the behavior of the signal and background samples near the edges of a detector it probably not optimal to use a simple fiducial volume cut to evaluate the physics potential of the experiment. To understand the optimization of the detector as a function of its transverse and longitudinal dimension we have applied the following procedure:

- a total mass of a detector is kept constant. A 50 kton number is used.
- detector length is calculated as a function of the transverse dimension assuming the average density $\rho = 0.7 \text{ g/cm}^3$.
- curves shown in Figs.1 and 2 are used as events density functions and the expected number of signal and background events is determined by integration over the detector volume.

The resulting FOM is shown in Fig.3. As a function of the transverse dimension of the detector the FOM exhibits a very broad maximum corresponding to the detectors in a range of $15 \times 15 \text{ m}^2$ to $25 \times 25 \text{ m}^2$. Smaller detectors suffer a deterioration of the performance due to the reduced signal and increased background around the edges of the detector. A drop of the FOM for very large (transversely) detectors comes from the loss of the signal and increase of the background at the downstream end of the detector.

Comparison of these results with the FOM for a hypothetical perfect detector indicates that in the optimized detector some 25% of the detector mass is lost to the edge effects.

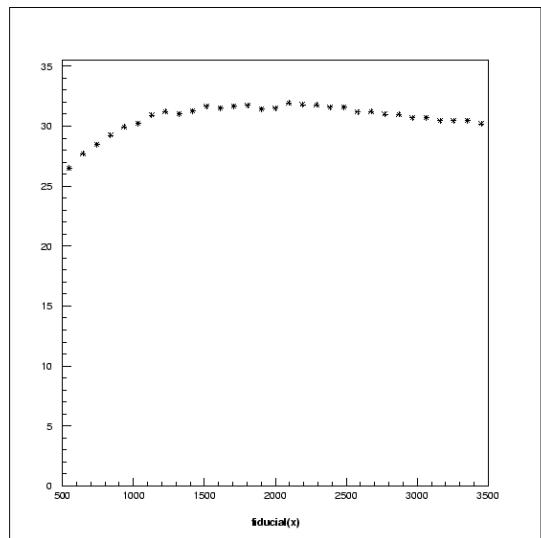


Figure 3: FOM as a function of transverse dimension of the detector, in cm

References

- [1] L. Camilleri, A. Para, The reconstruction of Numu and Nue Monte Carlo events, Off-axis Note-SIM-011
- [2] A. Para, RPC detector simulation using GMINOS, Off-axis Note-SIM-010